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Evaluating the sustainability of complex socio-environmental systems. the MESMIS framework

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Abstract

Sustainable development has become a leading target of scientific research and policy agenda. In the context of natural resource management, understanding and evaluating the performance of complex socio-environmental systems has become a challenge, and the design of more sustainable alternatives is a driving need. In addition, there is a need to translate the general principles of sustainability into operational definitions and practices.

This paper examines key methodological issues in the selection, transformation and aggregation of economic, environmental and social indicators for sustainability analysis. Specific reference is given to the MESMIS approach, a systemic, participatory, interdisciplinary and flexible framework for sustainability evaluation. The MESMIS framework has been developed by a multi-institutional team in Mexico and validated through its application to more than 20 case studies in Mexico and Latin America.

The MESMIS operative structure is a six step cycle. The first three steps are devoted to the characterisation of the systems, the identification of critical points and the selection of specific indicators for the environmental, social and economic dimensions of sustainability. In the last three steps, the information obtained by means of the indicators is integrated through mixed (qualitative and quantitative) techniques and multicriteria analysis, so as to obtain a value judgement about the resource management systems and to provide suggestions and insights aimed at improving their socio-environmental profile.

MESMIS attempts to generate a cyclic process which, by effectively integrating the evaluation into the decision making process, improves the likelihood of success in the design of alternatives and the implementation of development projects.

Keywords: Sustainability; Evaluation; Peasant farming; Indicators; Multicriteria analysis; MESMIS

1. Introduction

Operationalising sustainability requires new, qualitatively distinct, evaluation schemes that enable an integrated assessment of the ecological, social, and economic features and implications of a given project, technology or agroecosystem through the use of

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appropriate indicators. There is a critical need to develop indicators to assess the relative degree of sustainability of contrasting production systems, especially those throughout the rural sector of the developing world.

This task is especially important in the context of peasant Natural Resource Management Systems (NRMS)[3] that, despite being highly diverse, resilient and based on the renewable use of local natural resources, have been largely undervalued on the basis of criteria and indicators that focus on short-term economic benefits. Peasant agriculture, or peasant NRMS, is the primary source of staple food in developing countries, where perhaps as many as 1.5 billion people earn their livelihood from such activities (Rosset, 2001; Chambers, 1994). The complexity of peasant NRMS has been widely acknowledged, alluding to the tight interactions among the different activities related to natural resource management and the repercussion of such activities in the satisfaction of a multiplicity of economic, environmental and social objectives (Collison, 1983; Reijntjes et al., 1992; Brookfield, 2001).

Nowadays, there is general concern about the future of peasant agriculture and its acute economic, environmental and social degradation. During the last twenty years, development agencies, research institutions, NGOs and peasant organisations have been developing alternatives towards improving the sustainability of peasant NRMS. However, there is a need to design and apply integral evaluation strategies that enable the organisations to understand, value and strengthen such alternative NRMS. In other words, there is a need to translate the general principles of sustainability into operational definitions and practices.

In this paper, we present the MESMIS approach, a systemic, participatory, interdisciplinary and flexible framework for evaluating sustainability (Masera et al., 1999; Masera and López-Ridaura, 2000). Such an approach offers guidelines in the selection of specific environmental, social and economic indicators focusing on the important characteristics that steer systems performance. This approach also brings the opportunity to understand systems functioning and possibilities in an integrative manner.

2. The MESMIS evaluation framework in action

Indicators have been implicitly or explicitly used to understand the behaviour and dynamics of NRMS and, therefore, to assess their sustainability. Short-term oriented economic and agronomic indicators have generally been used to evaluate the performance of NRMS (e.g. focussing narrowly on maximizing yields and benefit/cost ratios). However, for sustainability analysis, there is consensus among different scientific disciplines and development sectors on the need to include environmental and social indicators and criteria as well as long-term oriented economic and agronomic indicators in the analysis.

During the 80's and 90's there was a rapid development of environmental indicators and, in a much lesser extent, social indicators. There have been many attempts to generate core sets (templates or checklists) of multidisciplinary indicators to asses the sustainability of NRMS (van Mansvelt and van der Lubbe, 1999; CIFOR, 1999) or indices that aggregate the information from a fixed set of indicators into a single value (e.g. Farmer Sustainability Index (Taylor et al., 1993) and the Indicator of Sustainable Agricultural Practice (ISAP) (Rigby et al., 2001)). Relatively fewer efforts have been devoted to the development of frameworks for the derivation of indicators sets (Smith and Dumanski, 1994; IUCN-IDRC, 1995; CIFOR, 1999).

The experience has shown that long lists of indicators are impractical. Also, there is a growing consensus that every NRMS is unique within its context and with its agents (or stakeholders), rendering fixed templates inappropriate. Using composite indices does not solve the problem, as there are controversies for defining the weight attached to each indicator. Another important drawback of this approach is that the result is a single numerical value, which offers little or no guidelines for further design of alternatives or strengthening of the NRMS. Methodological frameworks are urgently needed that can assist in the selection of appropriate indicators and in the integration and transformation of

[3] Natural ecosystems have been transformed by human beings by processes geared towards obtaining desired goods and services (such as food, fuel, and recreation). Within the context of this paper, such transformed ecosystems are termed Natural Resource Management Systems (NRMS).

Table 1
Characteristics of the NRMS and evaluation teams of five MESMIS key case studies in Mexico

Location of the case study	Systems evaluated (compared)	Characteristics of the evaluation team
1. Chiapas State Highlands	Organic vs. conventional small scale coffee production. Chiapas Highlands. The producers belong to the Majomut Ejido Union, organisation composed by 1053 *tzotzil* and *tzeltal* indigenous farmers	A team of nine persons from the Majomut Ejido Union plus four external persons, covering socio-economic and technical areas, and including promotors belonging to local villages
2. Michoacan State Highlands	Traditional vs. Commercial extensive hillside maize-cattle production subsystems	GIRA (a local NGO) in co-operation with National University (UNAM) and more than 15 farmers
3. Communities in the south-eastern States	Traditional (slash and burn) vs. alternative (maize-mucuna rotation) maize production	A peasant team formed by 16 representatives of 8 communities and a technical team of NGO and university fellows
4. Quintana Roo State	Forest Concessions (before 1985) vs. Communal (after 1985) Tropical Forest Management. The systems were implemented by the Organisation of forest *ejidos* (OEPFZM) integrated by 21 communities and a technical directive board	A team of three persons from OEPFZM plus four external persons, covering socio-economic and technical areas
5. South of Sinaloa State	Extensive vs. Alternative forage agrosilvopastoral systems	A team of nine researchers from the National Forest and Agriculture Research Institute (INIFAP) and Chapingo Agricultural University (UACh) with three external persons, covering socio-economic and technical areas

the information to set the basis for the design of more sustainable alternatives.

The Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS, for its acronym in Spanish) was developed by an interdisciplinary and multi-institutional team in Mexico as an attempt to translate the general principles of sustainability into operational definitions, indicators and practices in the context of peasant NRMS. The development of the framework is part of an integrated on-going project that aims at: (a) applying the MESMIS to different case studies in rural Latin America and other parts of the world; (b) generating and disseminating a set of key materials to facilitate the application and dissemination of the framework; (c) training individuals and institutions in evaluating the sustainability of NRMS.[4]

Since the beginning of the project in 1995, the MESMIS framework has attracted the attention of many NGOs, universities and peasant organisations from Latin America. It has been applied to more than 20 case studies, and included in 14 graduate and undergraduate programmes from Latin American and Spanish universities. Notably, five key in-depth case studies were carried out for a 2-year period in rural Mexico (Masera and López-Ridaura, 2000). Table 1 shows the location and main characteristics of the five case studies. The studies were chosen to be representative not only of the most common NRMS that occur in the Mexican context, but also to show contrasting differences in the composition of the evaluation teams, and in the procedures to develop and monitor indicators (Masera and López-Ridaura, 2000). Examples from these case studies are used throughout this paper in order to illustrate the MESMIS operational structure and results.

3. The MESMIS main premises and general structure

The MESMIS framework allows the derivation, measurement, and monitoring of sustainability

[4] For more information about the MESMIS project, the MESMIS evaluation framework and associated publications, please refer to www.oikos.unam.mx/gira.

indicators as part of a systemic, participatory, interdisciplinary, and flexible evaluation process adaptable to different levels of data availability and local technical and financial resources. The framework is based on the following premises.

- Sustainability is defined by seven general attributes of NRMS: (a) productivity, (b) stability, (c) reliability (d) resilience, (e) adaptability; (f) equity; (g) self-reliance (self-empowerment).
- Sustainability evaluations are only valid for: (a) a specific management system in a given geographic location; (b) a previously circumscribed spatial scale (parcel, production unit, community); (c) a previously determined time period.
- The evaluation of sustainability is a participatory process requiring an evaluation team with an interdisciplinary perspective. The evaluation team should include external evaluators and internal participants (farmers, technicians, community representatives, and others involved).
- Sustainability can not be measured per se, but rather can be seen through the comparison of two or more systems. The comparison can be made cross-sectionally (e.g. comparing an alternative and a reference system at the same time), or longitudinally (e.g. by analysing the evolution of a system over time).

4. Systemic attributes of sustainable NRMS

Conway (1987) and Garcia (1992) suggest that, for an interdisciplinary analysis to be effective, it has to produce insights that significantly transcend those of the individual participating disciplines. Systems theory holds that certain principles stand for all systems regardless of its hierarchical level (principles at one scale often apply to other levels) (Conway, 1987; Odum, 1994). Identifying a set of central systemic attributes (or properties) of sustainable NRMS that holds across disciplines or scales is therefore fundamental to keep both the evaluation of sustainability and the derivation of indicators theoretically consistent.

The MESMIS framework relies on a systemic approach, from which seven basic attributes for sustainability are defined: productivity, stability, reliability, resilience, adaptability, equity and self-reliance.[5] Operatively, sustainable NRMS are thus defined as those systems that:

- Achieve a high level of productivity through the efficient and synergistic use of natural and economic resources.
- Maintain reliable, stable and resilient production over time, ensuring the access and availability of the production assets; promoting the renewable use, restoration and conservation of local resources; integrating adequate temporal and spatial diversity of the natural environment with economic activities; incorporating risk prevention and reduction mechanisms.
- Provide flexibility (adaptability) to suit new economic and biophysical circumstances, by accommodating innovation and evolving learning processes, as well as through the use of multiple option strategies.
- Distribute, in an equitable manner, the costs and benefits of the system among the various stakeholders, ensuring both economic accessibility and cultural acceptance of proposed alternatives.
- Promote an acceptable level of self-reliance (self-empowerment), such that the system can control and respond to changes exerted from beyond its borders, while keeping intact its identity and values.

[5] Defining the properties or attributes of sustainable NRMS is a topic that has received some - but still incipient - attention. For instance, FAO, in its FESLM (Smith and Dumanski, 1994) defined productivity, security, protection, viability and acceptability as the pillars for conducting the evaluation of sustainability. Other frameworks define their attributes in a more systemic approach. For example, according to the Inter-American Council for Sustainable Agriculture (ICSA, 1996), the most important attributes of a sustainable management system include: (a) the maintenance of resource availability over time; (b) the system's adaptability and flexibility; (c) its vigor, resilience and stability; (d) its responsiveness to changes (both internal and external); (e) its self-reliance; (f) its empowerment. Conway identifies four basic attributes for sustainable systems: productivity, stability, sustainability, and equity (Conway, 1994). This systemic vision for identifying the attributes of sustainability provides a more consistent theoretical framework and has been applied to case studies (González-Esquivel, 1998).

5. Linking indicators to attributes of sustainable NRMS

The set of general attributes for sustainability provides the overall framework for guiding the derivation of indicators during the evaluation process. It also helps assure a compact and consistent set of indicators, as we will show in the following sections. The "logic" structure of the evaluation process is illustrated in Fig. 1. The Natural Resource Management System (e.g. rainfed corn cultivated by small farmers) to be evaluated is first chosen, clearly indicating the unit of analysis as well as the spatial and temporal scales, and socio-environmental context of the evaluation (shaded box). Associated with the NRMS to be evaluated are a series of specific critical aspects or features for system sustainability, which help "ground" initially the general attributes of sustainability (first and second arrows in the diagram). These critical features might be of an environmental, social and/or economic nature (noted in the diagram as "evaluation areas"). For each evaluation area, diagnostic criteria and indicators are finally defined, which can be easily traced back to the different attributes of sustainability. This procedure assures

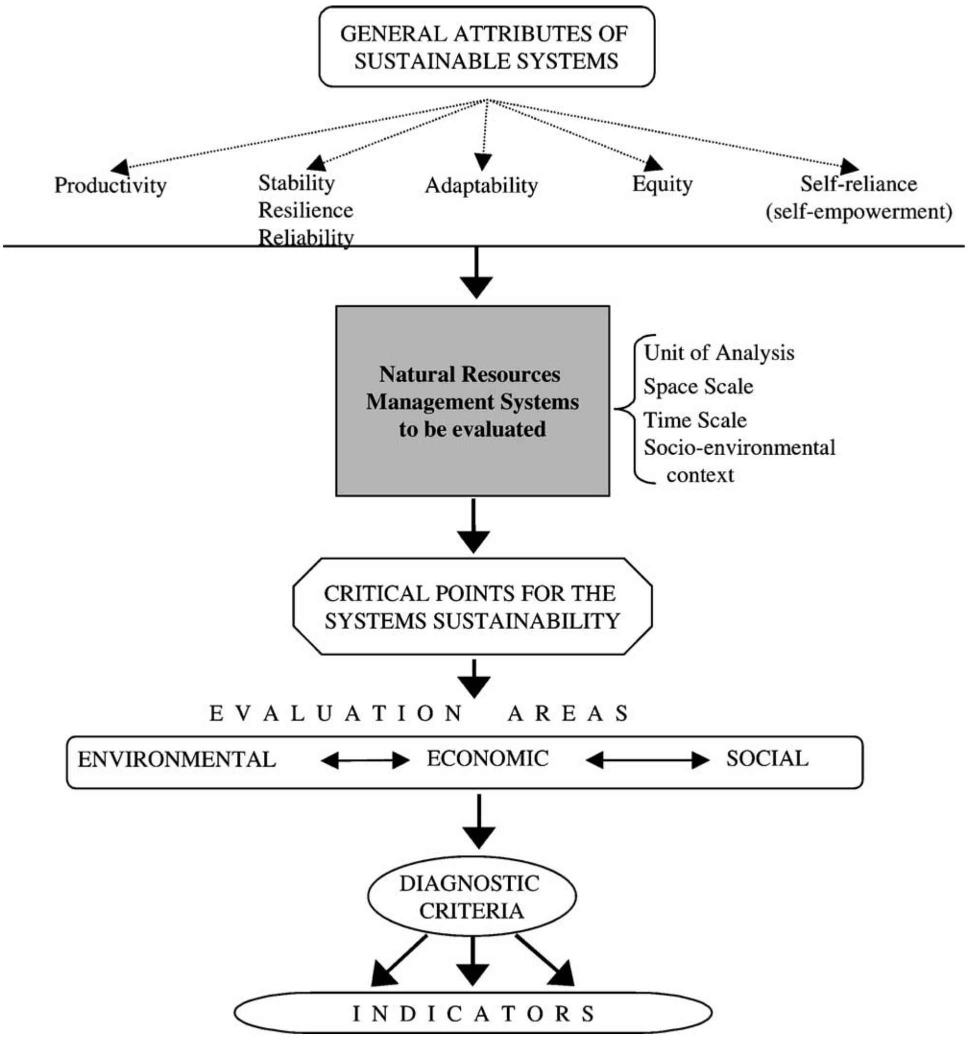

Fig. 1. The MESMIS evaluation framework: linking attributes for sustainability to indicators.

a consistent relationship between sustainability indicators and the general attributes of sustainable NRMS (Fig. 1).

6. The MESMIS operational structure

The operational structure of the MESMIS is conceived as a cycle consisting of six steps (Fig. 2). The first three steps are devoted to the characterisation of the systems, the identification of critical points and the selection of specific environmental, social and economic indicators. In the last steps three, the information obtained through the indicators is integrated using quantitative and qualitative analysis techniques, which allows obtaining a value judgment for the NRMS evaluated and suggesting ways to improve the socio-environmental profile of these systems. These suggestions and recommendations trigger a new evaluation cycle that starts re-characterising the system (Step 1 T_2). A brief description of the different steps is presented below.

6.1. Step 1: Definition of the evaluation object

This step includes: (a) identifying the management systems under scrutiny, as well as their socio-environmental context and the spatial and time scope

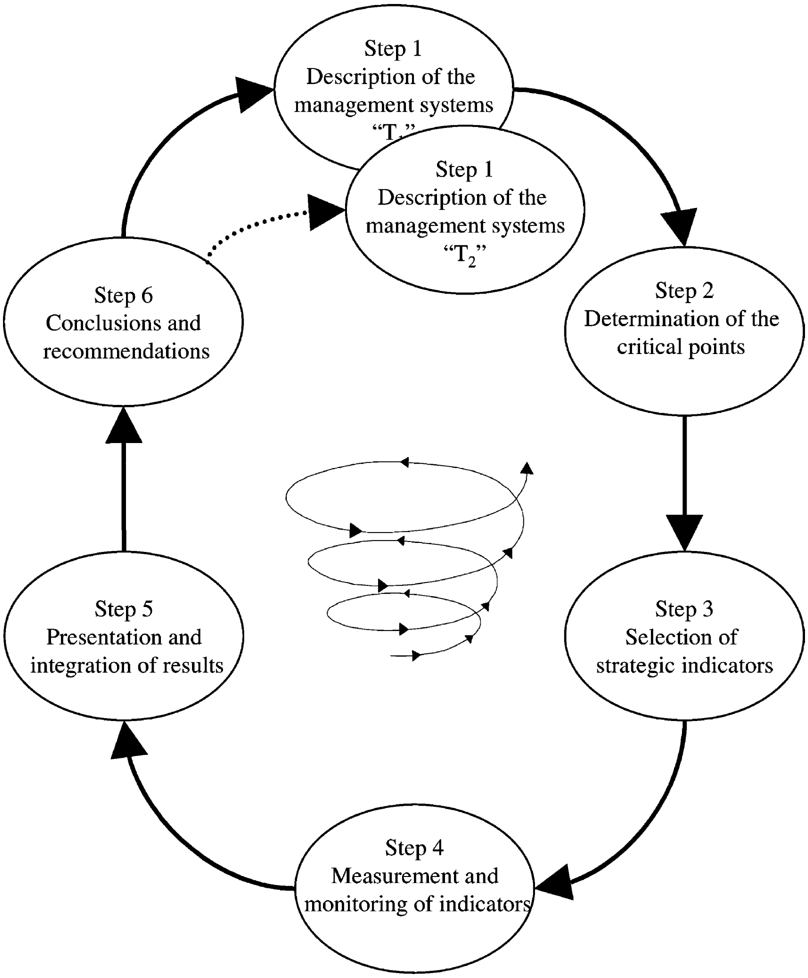

Fig. 2. The MESMIS evaluation cycle.

of the evaluation; (b) characterising the reference management system in the region (i.e. the prevailing system, whether traditional or conventional); (c) characterising the alternative system or systems. In the case of longitudinal studies, the system should be characterised both before and after the modifications are introduced. Characterising management systems, or agroecosystems, must include an accurate description of the (i) components of the system, (ii) the system's inputs and outputs, (iii) the productive activities involved in each system as well as (iv) the main social and economic characteristics of producers and the type of organisation. The evaluation teams of the different case studies often generated a summary table and a general flowchart with the characteristics of the systems. Fig. 3A shows the flow chart constructed for the characterisation of the typical household production unit in Casas Blancas, which consists of three main components (agro-silvo-pastoral subsystems). These components at the same time are regulated and managed by the familiar unit. Fig. 3B shows the characterisation of the two agro-pastoral subsystems (traditional and commercial) made by the evaluation team in Michoacán, Mexico (Astier et al., 2000).

6.2. Step 2: Determination of the system's critical features

The critical features of a system are those aspects that enhance or constrain system's attributes i.e.

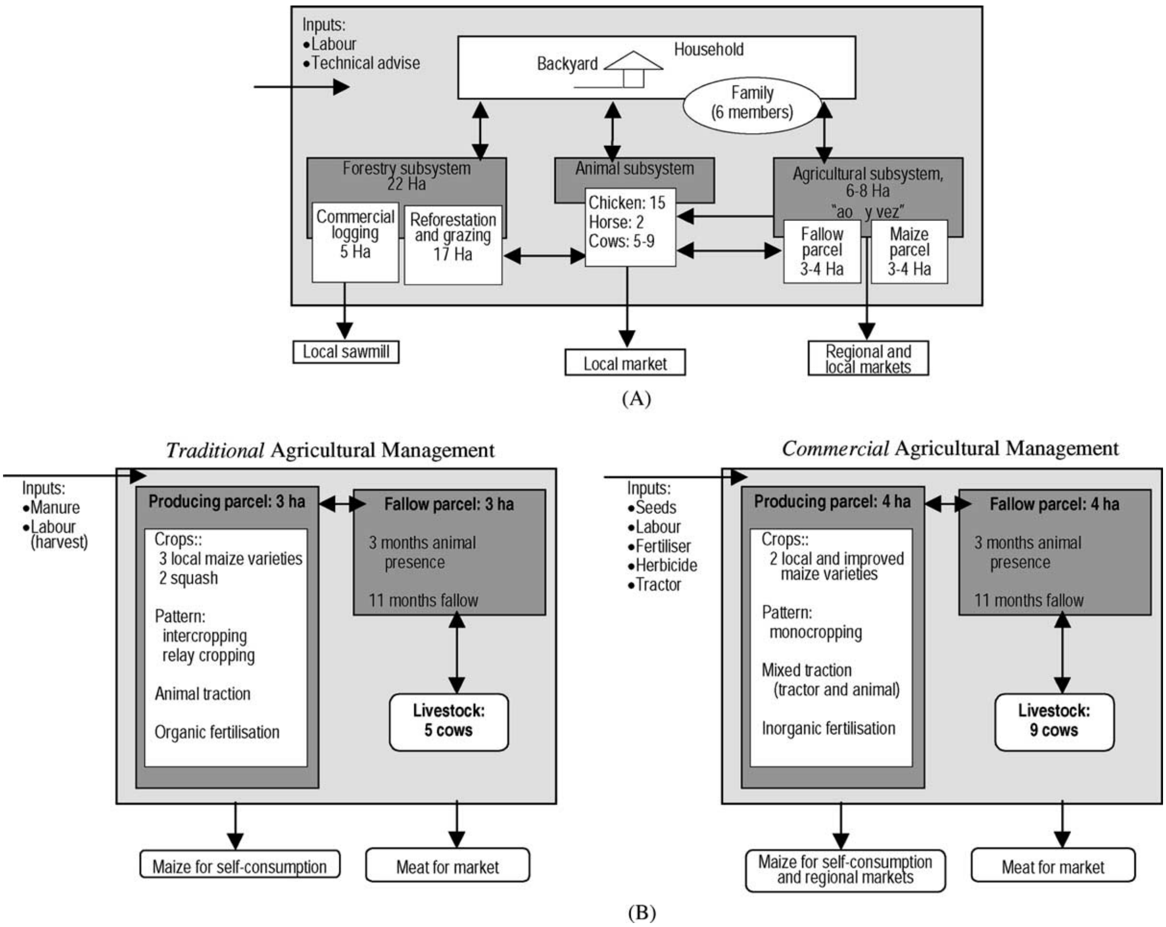

Fig. 3. Characterisation of an Agro-silvo-pastoral Management System (A) and the comparison of two agro-pastoral subsystems (B), in the Casas Blancas, Mexico. (Astier et al., 2000).

productivity, stability, resilience, reliability, equity, adaptability, and self-reliance. Focusing the attention on the critical features confers handling dimensions to the problem by concentrating the evaluation process to such aspects.

Some key questions involved in identifying critical points include: What makes the NRMS vulnerable? What presents particular problems? What constitutes the strongest, most prominent features of the NRMS? These features, or critical points, exist as the environmental, technical, social or economic factors or processes that, isolated or in combination, have a critical impact on the survival of the management system. Table 2 lists the critical features, grouped by sustainability attribute, which have frequently appeared in the application of the MESMIS framework to case studies.

Once the critical features of the NRMS are identified, they should be linked to the different sustainability attributes, so as to assure that all attributes have been addressed in the evaluation. Critical points may be related either to a single attribute, or to a set of attributes. For example, a serious problem in a number of NRMS's in Mexico is the scarcity of labour and its high opportunity cost due to migration, which has direct repercussions in system productivity, but also in its stability and self-reliance.

6.3. Step 3: Selection of strategic indicators

In order to select a set of strategic indicators during the evaluation process, a two-level approach has proved useful. The process starts by defining first a

Table 2
Common critical points, diagnostic criteria and indicators utilised in the MESMIS case studies

Attributes	Critical points	Diagnostic criteria	Indicators
Productivity	Low crop yields and low profits	Efficiency (yields and profits)	Yields, quality of products, cost/benefit ratio
	High opportunity cost for labour	Return to labour	Economic return to labour
Stability, resilience, reliability	High degradation of natural resources	Degradation or conservation of resources	Nutrient balances, erosion levels, biophysical characteristics of soils (i.e. compaction, percentage of organic matter), yield trends
	Highly diversified systems (or poorly diversified systems)	Agrodiversity	Number of species grown, income per species
	High vulnerability of production	Crop damages	Incidence of pest, diseases and weeds
	Highly unstable prices of inputs and outputs	Variability of input/output prices	Variation of input and output prices (e.g. coefficient of variation of input/output)
Adaptability	Low technological or institutional innovation/adaptation	Ability to change and to adopt new technology	Adoption of new alternatives and/or farmers permanence within a system, capacity building activities, proportion of area with an adopted technology
Equity	Low income farmers Unequal distribution of benefits and costs	Distribution of costs and benefits	Initial investment costs Share of benefits by different farmer groups
Self-reliance	Deterioration of farmers' and costs	Organisation and participation	Participation in the design/implementation and evaluation of alternatives, degree of participation in the decision-making process
	High indebtedness of local farmers	Degree of dependency from external inputs	Cost of external inputs, use of external resources

Note: a critical point may be related to one or more attributes and be assessed by more than one indicator.

set of diagnostic criteria. These criteria help begin "grounding" the general attributes of sustainability, and represent a level of analysis more detailed than attributes, but more general than indicators. Diagnostic criteria serve as a necessary intermediary link between attributes, critical points and indicators, that enables a more effective and coherent evaluation of sustainability. Having defined the diagnostic criteria, indicators may be subsequently identified and selected. Table 2 shows some of the most common diagnostic criteria and indicators used in the different case studies in which the MESMIS framework was applied in Mexico.

The set of indicators derived in the evaluation of NRMS should cover the seven sustainability attributes as well as the social, economic and environmental dimensions. For example, for the stability attribute, common diagnostic criteria are "resource conservation" and "diversification"; in the environmental area an appropriate indicator for the first criterion could be, depending in the specific case, the level of soil erosion or the content of soil organic matter (or the population of beneficial insects); in the economic area an indicator for the second criterion could be market diversification.

Once the list of all potential environmental, economic, and social indicators has been compiled, it is important to make a final selection in order to generate a set of strategic indicators that can be measured or estimated. As suggested by De Camino and Muller (1993), the final set of indicators should be robust but not necessarily exhaustive, in other words, the list must include solely those indicators that reveal critical features on the NRMS under analysis. Table 3,

Table 3
Indicators used for evaluating the sustainability of two coffee production systems in the Highlands of Chiapas, Mexico (*Union De Ejidos Majomut*) (Pérez-Grovas, 2000)

Attribute	Diagnostic criterion	Strategic indicators	Measurement method
Productivity	Efficiency	Yields	Sampling
		Produce quality	Random sampling to determine percent of aborted berries and defective berries
	Profitability	Marginal cost/benefit	Cost-benefit analysis
		Labour demand	Socio-economic survey
		Net income/total income	Socio-economic survey
Stability, resilience, reliability	Biological diversity	Number of managed species	Surveys of flora
	Economic diversity	Income from non-coffee crops	Census of non-coffee plants and products
		Market diversification	Coffee marketing process
	Biological vulnerability	Pest incidence	Random sampling in plots
		Erosion	Measuring in runoff plots
		Nutrient balance	Soil, compost and berry analyses
	Economic vulnerability	Input availability	Technical monitoring dossier per plot
		Fluctuations in coffee prices	History of coffee prices
	Social vulnerability	Permanence of coffee producers in the system	Majomut coffee producers' registry
Adaptability	Capacity for change	Producers and area cultivated per system	Majomut producers' registry
Equity	Distribution of benefits, and decision-making power	Decision-making mechanisms	Interviews with Majomut Directive Board
		Distribution of returns and benefits	Institutional survey
Self-reliance	Participation	Attendance to assemblies and other events	Institutional survey
	Training	Number of producers trained	Quantification of training courses
	Self-sufficiency	Reliance on external resources	Financial statistics of Majomut

presents the final set of strategic indicators used during the evaluation of two coffee production systems (organic and conventional) in the Highland of Chiapas, Mexico (Pérez-Grovas, 2000).

6.4. Step 4: Indicator measurement and monitoring

Indicators may be measured and monitored in many different ways. Since sustainability refers to the system's behaviour over time, the emphasis must be on those data-gathering procedures that enable the monitoring of processes during a given time period, the analysis of historical data series, or the modelling of some variables.

In the MESMIS case studies, several techniques have been used, mainly depending on the characteristics of the evaluation teams and the technical, economic and time resources available for the evaluation. The measurement techniques have included a great variety of tools, including: (a) literature review regarding regional environmental characteristics, access to meteorological databases (rainfall, natural disasters, etc.) and compilation of historical data on crop yields; (b) direct measurement (e.g. total biomass and crop yields, soil properties, fauna and flora species diversity); (c) setting of monitoring devices in farms (runoff plots to measure erosion, insect traps); (d) construction of a matrix of technical coefficients to obtain desired technical characteristics for each system (labour demand, inputs, costs and productivity); (e) simulation models (e.g. the EPIC model aimed at estimating the erosion-productivity relationship) in order to determine the expected long-term behavior of a system's yields; (f) comprehensive review of the literature of regional socio-economic characteristics (e.g. historical review of the changes in the price of inputs and harvested products of the management system); (g) surveys to institutions and households, by organisation or community (e.g. to determine the opportunity cost of family labour); (h) open-ended and semi-structured interviews with farmers, key community members and project staff; (i) participatory group techniques in the field, workshops and farm's visits.

The experience gained with the MESMIS case studies, shows that at least two cropping cycles and a combination of techniques are required for a sound evaluation process. Also, while the MESMIS framework has provided sufficient flexibility to adapt to different levels of financial and technical resource availability, evaluation projects with sufficient funding and a balanced evaluation team often reach greater accuracy in the analysis.

6.5. Step 5: Synthesis and integration of results

In this step, the results obtained by monitoring the indicators are summarised and integrated. Typically, at this stage, the evaluating team is dealing with a dozen or two of highly diverse and complex indicators that describe a range of environmental, economic and social factors, expressed in either qualitative or quantitative terms. Developing procedures to effectively integrate results is not an easy task.

Quantitative, qualitative, and graphical or mixed procedures have been used to integrate results. Each technique has its relative advantages and disadvantages. For example, quantitative or formal techniques are well-developed and allow the detailed analysis of complex situations, but usually require advanced training in statistics and mathematics. Qualitative procedures and tools are, often, easier to use; however, frequently their graphic presentations are attractive but of dubious quality. It should be understood that switching from quantitative to qualitative procedures does not imply a loss of analytical objectivity. When properly designed, qualitative techniques may provide more effective methods for identifying problems than complex numerical analysis, as in the latter case it is often not clear how the final scores were obtained. Likewise, switching from qualitative to quantitative procedures does not necessarily imply an increased objectivity or accuracy in the analysis, though this change provides a numerical outcome.

In order to achieve an adequate integration and synthesis of the results, the MESMIS evaluation teams have followed five stages: (a) placing the results by indicator and system into a single table or matrix, using the original units of each indicator; (b) determining thresholds or baseline values for each indicator; (c) building indices for each indicator, according to baseline values or thresholds. These indices may be built on both qualitative (e.g. high, medium and low) and quantitative data; (d) putting all indicators together, using graphs and tables; (e) examining the connections—or relationships—between indicators including the positive and negative feedback.

One tool that has proved useful to graphically integrate and monitor the different indicators is the AMOEBA diagram (Brink Ten et al., 1991). This diagram shows, in qualitative terms, to what extent the objective has been met for each indicator, and it enables a simple, yet comprehensive, graphical comparison of the advantages and limitations of the management systems being evaluated. Fig. 4 and Table 4 show the AMOEBA derived for a MESMIS case study in the northern Mexican state of Sinaloa, in which two agro-silvo-pastoral systems were evaluated (Perales et al., 2000).

6.6. Step 6: Conclusions and recommendations

With this step, the first cycle of the evaluation comes to an end. Step six recapitulates the results of the analysis to judge how the different systems compare in terms of sustainability. With the help of graphic techniques (such as the AMOEBA diagram), the evaluation teams discuss and analyse the main limitations and possibilities of the reference and alternative systems in order to strengthen them. In general, the recommendations to improve the sustainability of the systems have included: (a) the modification or introduction of

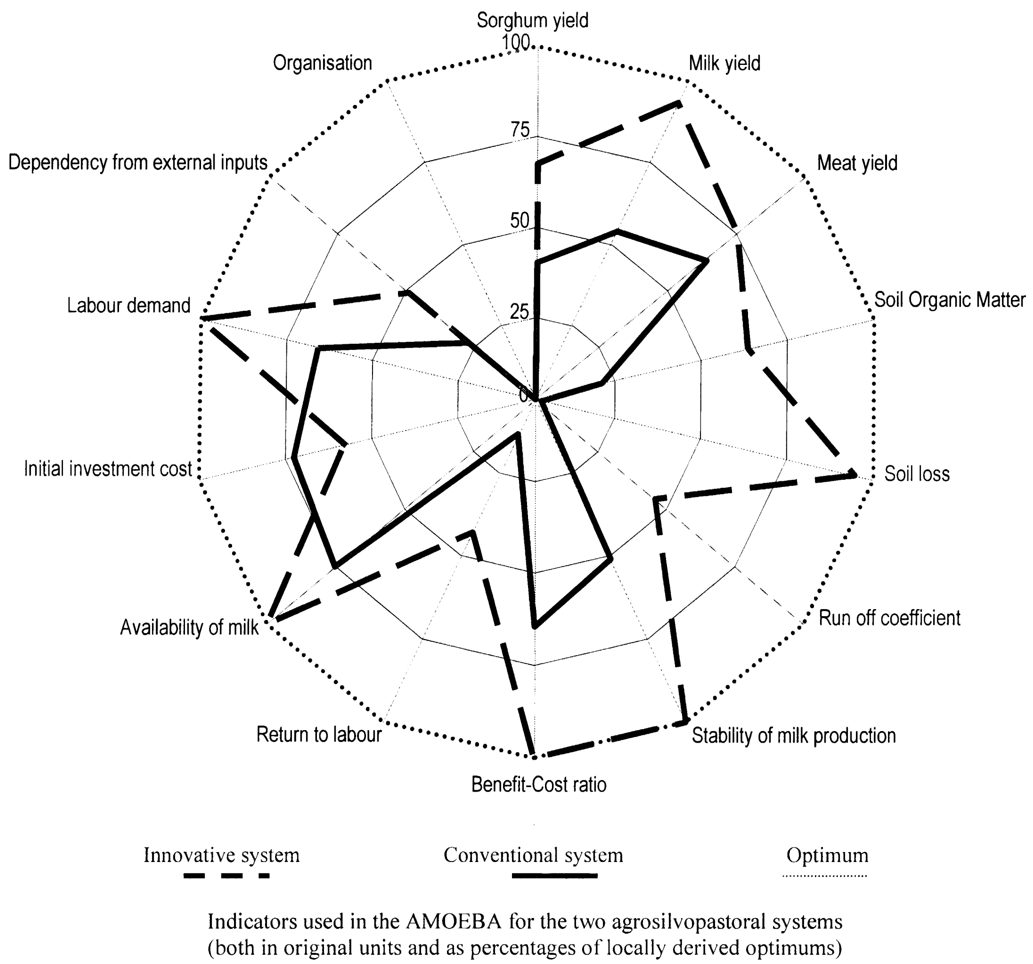

Fig. 4. Integration of sustainability indicators for two agrosilvopastoral systems from Northern Mexico using an AMOEBA diagram (adapted from Perales et al., 2000). The figure shows the diagram and the data used to construct it. Indicators and optimums were derived by the local evaluation team and are presented both in its original units and as percentages relative to the optimum.

Table 4
Indicators used in the AMOEBA for the two agrosilvopastoral systems (both in original units and as percentages (in parenthesis) of locally derived optimums)

Indicator	Innovative system	Traditional system	Optimum (100%)
Sorghum yield (t/ha)	6.7 (67)	3.9 (39)	10
Milk yield (l per cow per year)	1400 (93)	790 (53)	1500
Meat yield (kg per calf)	150 (75)	125 (63)	200
Soil organic matter (%)	1.25 (63)	0.39 (20)	2.00
Soil loss (t/ha per year)	4.74 (95)	39.55 (0)	3.0
Runoff coefficient	0.253 (45)	0.464 (0)	0
Stability of milk production	High (100)	Medium (50)	High
Benefit–cost ratio (*B*/*C*)	1.5 (100)	0.96 (64)	1.5
Return to labour (RMO) ($ per day)	41 (41)	11 (11)	100
Availability of milk (months per year)	12 (100)	9 (75)	12
Initial investment cost (calves)	10.5 (60)	5.5 (73)	7.5
Labour demand (workers per day)	1.7 (100)	1.1 (65)	1.7
Dependency from external inputs (%)	52 (48)	75 (25)	0
Organisation	Low (0)	Low (0)	High

a new strategy within the NRMS (e.g. modification of the livestock number or the feeding strategy, or new commercialisation strategies); (b) the design of new alternative systems with the introduction of new components (e.g. green manure or cover crops); (c) the identification of knowledge gaps and establishment of priorities for research and development in the area.

This step is also the phase in which to reflect upon the evaluation process itself, and put forward strategies and recommendations to initiate a new evaluation cycle in qualitatively different conditions (time T_2 in Step 1, Fig. 2). These recommendations allow establishing priority actions (weighing needs and alternatives) to improve the NRMS sustainability. In methodological terms, the recommendations from the evaluation teams have mainly focused on: (a) the inclusion of all subsystems in the subsequent evaluation cycle (e.g. the forest subsystem, if the evaluation concentrated only on the agriculture subsystem); (b) the strengthening of interdisciplinary approaches and modification of indicators for specific issues; (c) the increase in the participation of different stakeholders during the entire evaluation process, as well as, (d) the articulation of various spatial scales of analysis.

To carry out this step properly, the evaluation teams have employed participatory techniques with farmers, practitioners, researchers and other individuals involved in the evaluation process. In this way, the needs and priorities of all stakeholders (producers, development workers, researchers, decision-makers, etc.) are taken into account.

7. Conclusions

Promoting the sustainable management of natural resources is a compelling task that requires new approaches and strategies. A key precondition for fulfilling this objective is the development of evaluation frameworks and indicators that make explicit the environmental, economic, social and cultural advantages and disadvantages of the different NRMS. We have argued that, through the development of appropriate indicator sets, these frameworks need to assess how the proposed options improve not only the system's productivity or profitability, but also the stability, resilience, and reliability of resource management systems, as well as its adaptability, equity and self-reliance.

It is essential to try to develop qualitatively distinct methodological frameworks where, among other things, the integration of the social, economic and environmental dimensions occurs during the evaluation process itself, and not in the simple juxtaposition of the results that were obtained for every indicator or evaluation area. Moreover, dealing with indicators that are hard to aggregate, quantify or extrapolate, that are usually vaguely or inaccurately determined, and that involve a range of stakeholders and perspectives, should be perceived as a challenge, rather than an obstacle for the evaluation process.

The application of the MESMIS framework to peasant NRMS has pointed to several issues that deserve further research and development in the topic of sustainability evaluation and indicators.

7.1. *Sustainability attributes*

It is important to continue the discussion about the fundamental systemic properties that enable rendering the concept of sustainability operative. In this domain, social aspects, and notably political issues, do require a much more extensive discussion.

7.2. *The integration of indicators and results*

It is important to find better techniques for integrating the environmental and socio-economic aspects, and for integrating the results of the evaluation. Multicriteria analyses need to be designed in order to avoid extremely complicated techniques that can only be understood by experts. Urgently needed are techniques that enable a clear and simple presentation of the different dimensions of the NRMS, showing the relations between different indicators, and also able to deal with vaguely (fuzzy) or imprecisely determined indicators rather than concentrating on the weighing of indicators and in finding "optimal" solutions.

7.3. *The interrelation of indicators*

The analysis of interrelations among sustainability attributes and among indicators deserves priority attention in the near future. In fact, most efforts so far have been directed to determine which indicators should be individually measured or optimised, without a careful examination of strategies aimed at increasing the sustainability of the system *as a whole*. Notably, there is a need to analyse how indicator interrelations may lead to trade-offs—e.g. when an increase in productivity may lead to a decrease in stability or resilience—or conversely to synergetic effects, so as to define a minimum set of truly robust indicators.

7.4. *The articulation of evaluation scales*

Achieving an adequate articulation between the different scales of evaluation is another important challenge for sustainability evaluations. In the MESMIS framework, we have focused mainly on local issues, from the farm plot to local villages. Future exercises should link different evaluation scales. An important question to this respect is how to achieve some consistency between local level and regional (or even national or global) level evaluation frameworks and indicator sets.

7.5. *Making sustainability evaluation a truly participatory exercise*

It is essential to use participatory techniques to incorporate more satisfactorily the priorities and perspectives of natural resource managers in the evaluation process. To this respect, it would be useful to do further work on the decision-making process, so as to take into account the perspectives of all management system stakeholders. Likewise, there is a need to improve the process of threshold or baseline value determination for each indicator, so that they become activity planning guides and ranking axes for the people in charge of natural resource management.

The MESMIS project is working to overcome some of the aforementioned challenges by means of a comprehensive strategy that involves developing and disseminating didactic and research resources on sustainability evaluations, undertaking detailed case studies for representative management systems in Latin America and other parts of the world, training individuals and organisations in the use of the methodology, developing a sustainability database and exchanging experiences with other groups. These activities will provide a valuable feedback and more experience in the application of the evaluation framework, advancing both theoretical and practical critical aspects. Moreover, the exchange with other groups will help in establishing common agendas for further examining the theoretical aspects or for improving the operational aspects of the evaluation.

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